Anesthesia eJournal /AEJ
Volume 3 Issue 2 2015

Reliable Needle Visualization During Ultrasound-Guided Regional Procedures: A Simple Solution to Steep-Angle Echogenicity Loss Based on Target Depth

Jonathan Kline, CRNA, MSNA

Affiliation:

Director of Education at Twin Oaks Anesthesia Services. contact – TwinOaksAnesthesia@gmail.com

Funding/Conflict of Interest Disclosure:

None

Abstract

Ultrasound-guided regional anesthesia is now recognized as the evolving alternative to standard landmark-based techniques for nerve blockade and vascular access. The limitations of this technique begin to be recognized, however, as needle angles increase beyond 30 degrees, as commonly used for deep injections. This limitation remains difficult to overcome, especially for novice users. Loss of needle visibility on the monitor screen remains a source of frustration for many providers, leaving them confused as to ultrasound's true utility. This article explores a simple, reliable technique for improved needle visibility on any ultrasound machine through triangulation of 3 points using the law of sines. The three points of ultrasound triangulation are (1) the location of the ultrasound probe, (2) the nerve target, and (3) the site of needle entry. The location of the ultrasound probe is chosen by the user and the depth to the nerve is displayed by the ultrasound machine. The third point, the needle entry site, is based on the law of sines to ensure a needle entry angle of less than 30 degrees. This approach can simplify a challenging aspect of ultrasound-guided regional techniques.

KEYWORDS: anesthesiology, increased needle visualization under ultrasound, law of sines, needle visualization, needle enhancement, ultrasonography

INTRODUCTION

Ultrasound-guided regional anesthesia is now recognized as the evolving alternative to standard landmark-based techniques for nerve blockade and vascular access. Since the first documented anesthesia application of ultrasound in 1978 by La Grange,[1] techniques have improved and clinical use has increased. Ultrasound use has shown increased success, and to some extent increased safety, versus blind techniques.[2] It seems logical that the ability to actually visualize the needle during regional anesthetic placement allows for greater safety and success, although current literature is slow to support the former. The limitations of ultrasound-guided regional anesthesia began to be recognized, however, as needle angles increase, as is common for deep injections. This limitation remains difficult to overcome, especially for novice users. Loss of needle visibility on the monitor screen remains a source of irritation for many providers, leaving them confused as to ultrasound's true utility. If the angle at which the ultrasound waves hit the needle shaft is from a relatively parallel origin, such as in shallow injection techniques, the needle can be displayed as a hyperechoic (bright white) line that is easy to visualize. As the angle departs from parallel and exceeds greater than about 30 degrees, the ultrasound wave fails to return to the probe. This reliably happens in all ultrasound systems regardless of make or manufacturer. This in essence describes the physics problem associated with visualization during steep needle angle paths.

We sought a simple, easily incorporated and cost-effective solution to this problem. One method would be to add software to the system allowing the probe to adjust the beam angle to compensate for needle approaches greater than 30 degrees. Another cheaper, more reliable, and less complex method would be to simply adjust the needle angle. Because depth readings are a fairly standard display in the ultrasound industry, we decided to use this single variable to provide a map for allowing increased needle visualization based on this piece of readable information.

REVIEW OF THE LITERATURE

A current review of the literature was conducted by using the terms "increased needle visualization under ultrasound," "law of sines," "needle visualization," and "needle enhancement."

The ultrasound system processor displays a needle by way of specular reflection. Chan and Perlas[3] describe specular reflection as the processing of ultrasound wave return from an object that is long and smooth. The wave return to the probe for processing is in a single direction. The object must be in an orientation to the ultrasound beam that is relatively similar to the angle of origin. "There is increased signal wave return as the needle is more parallel to the ultrasound's probe face". This orientation ensures that the majority of the emitted waves are received and processed.[4] Specular reflection differs greatly from what is known as diffuse reflection. Chan and Perlas[3] describe diffuse reflection as poor return of ultrasound waves from an object that is irregular in nature or has steep angles. Steep needle angles encourage wave refraction, or diffusion of ultrasound waves away from the probe. Because these waves fail to return to the probe, less information is available for processing, thus resulting in poor image resolution.[4]

There is a unique element in the processing of hollow needle ultrasound return waves. The beam strength exceeds the strength of the needle shaft on the away path but not on the return path to the probe. Ultrasound waves become trapped within the lumen of the needle and return to the probe in a delayed fashion. The delay occurs because the waves easily penetrate the outer lumen of the needle on the away path but are reflected back to the lumen multiple times on the return path. This happens in a repeated fashion until the waves manage to penetrate the needle's superficial wall and return to the probe. The bouncing around of these waves produces a delay in the return time. These wave bursts return in a staggered fashion, producing an image of a repeating needle on the screen. This was described by Reusz et al4 as an artifact occurring at increasing depths until the needle angle changes or the wave strength is decreased. This is known as reverberation artifact.[5]

As early as 2004, needle visualization loss was reported. Schafhalter-Zoppoth and colleagues5 noted that, as the needle angle increased (or became steeper), needle visibility decreased. This was a reproducible finding in human tissue, but those authors did not use a variety of ultrasound equipment. Miura et al6 also described needle visualization loss at particular angles. An important element from this article was the clear loss of visualization with a linear probe at between 30 and 45 degrees.[6] This article was probably the first report making the link between linear probe use and steep needle angle visualization loss. This is important to clinical practice because most scans and needle techniques commonly used in anesthesia care are performed with a linear probe. The characteristic of increased insertion and visualization loss is not unique to needle insertion. Junji et al[7] observed that peri-neural catheters also exhibit similar visual loss during ultrasound techniques when placed at steeper angles.

Interestingly, the visual loss is less pronounced with a curvilinear probe at steeper angles. Similar results were reported by Abbal and colleagues.[8] Hocking et al[9] observed that the use of cadaveric tissue versus commercially available alternatives to assess needle visibility differed in echogenicity. He noted that phantoms and gel mediums had a low background echogenicity and would therefore exaggerate needle visibility during skills acquisition. This differed from fresh-frozen cadavers in that they retained greater lifelike clinical echogenicity. This is important when evaluating needle angle visual loss, because the medium in which the evaluation occurs influences needle visibility.[9] In essence, this means that techniques are easier to perform on simulators and gel mediums than on actual human tissue. It has yet to be evaluated whether ultrasound-guided skills acquisition is made more efficient by the addition of formal training on simulators prior to actual patient care, although this seems to make sense.

Hebard and colleagues[10] quantifiably linked steep needle angles to visual loss. In this important article, they also concluded that every 10-degree increase in needle angle steepness resulted in a 12% visual loss. Stated another way, if the needle angle exceeds about 40 degrees, visualization of that needle decreases by about half. Weismann et al[11] confirmed earlier findings that correlated visual loss with steep angle insertion. Those authors also observed that this visual loss was less severe if the needle was visualized by use of ultrasound beam compound imaging.[11]

This literature review points to a few interesting correlations. If needle angles exceed about 30 to 40 degrees, visualization ultimately decreases. The only way described in the current literature to alleviate this problem is to use some sort of ultrasound beam alteration or enhancement, or to change to a curved probe (which is usually unsuitable for most anesthesia-related procedures).

DESCRIPTION OF TECHNIQUE FOR IMPROVED NEEDLE VISIBILITY

We developed a method whereby a clinician can place an in-plane needle under any ultrasound beam and be able to visualize it, regardless of depth of the target, age, or complexity of the machine. This method can allow even the most inexperienced providers access to readily viewable needles on the monitor during regional and vascular procedures. The criteria for this new method are as follows:

1) The needle angle cannot exceed 30 degrees.
2) The needle guidance software and enhancement cannot be engaged, as there are too many variables to consider regarding current and older systems.
3) Only standard block needles, which are easy to obtain and cost-effective, should be used.

We first determined the pieces of information easily accessible by virtually all ultrasound machines. The commonality was depth. Reading the depth on the screen was nearly universal among the surveyed machines in current practice. The second piece of information known from the literature review was that 30 degrees seemed to be the maximum allowable angle to produce perfectly readable needle echogenicity. This cutoff applies to needles placed in-plane. Although a great many other pieces of information were available, they were not common to virtually all machines. Thus, on the basis of these pieces of information, we sought to complete a simple method to allow anyone to produce readable needles at any depth.

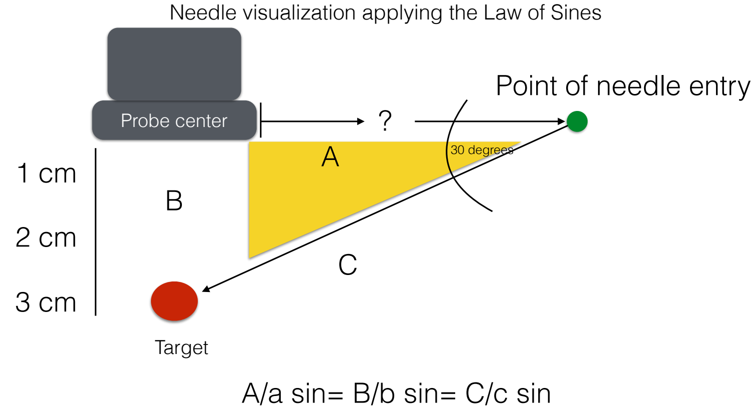
The solution was described as a simple inverted triangle (Figure 1). The base of the triangle became the probe interface with the skin. The height of the triangle became the depth to the target of interest. This left only the distance from the probe to begin needle entry, keeping in mind that the needle could not exceed 30 degrees of approach to the target.

Figure 1. Triangulation of 3 points using the law of sines: (1) the location of the ultrasound probe, (2) the nerve target, and (3) the site of needle entry.

Figure 2 shows images revealing the difficulty of needle visualization during steeper needle angles. Note that in image A, the needle shows up displaying strong echogenicity. This is an excellent example of an entry that is less than 30 degrees. Image B shows the same needle on the same patient, but visualization of that needle is markedly decreased. Image B shows the visual loss as reduced echogenicity of the needle shaft at a larger insertion angle.

Figure 1

Needle visualization applying the Law of Sines



Jonathan P. Kline, CRNA

Figure 2. Images A and B are actual patient (in vivo) pictures captured during an ultrasound-guided regional procedure. (Images from Jonathan Kline, CRNA.)

Image A

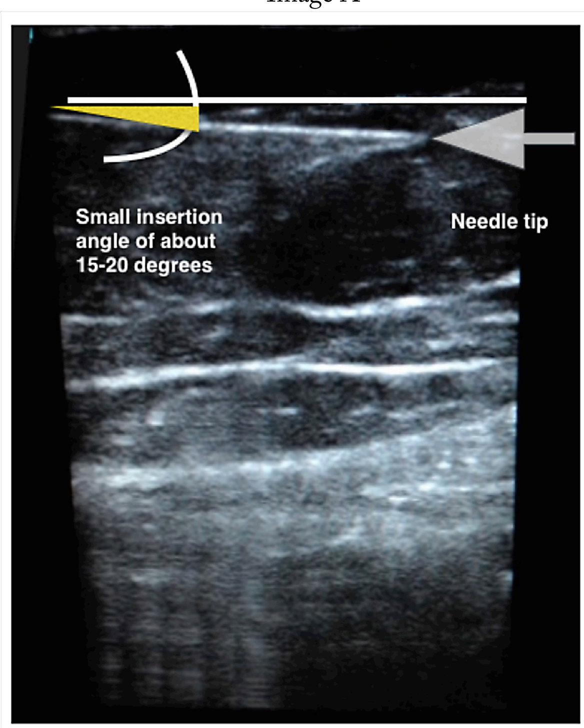


Image B

In solving this triangle problem, we used the law of sines. Although there are many variations of this solution, we used a simple technique that allowed for a simple formula to be used based solely on the depth of the target structure. For example, if the target structure is 4 cm in depth and the approach cannot exceed 30 degrees without signal loss (leading to decreased needle visualization), the skin must be entered at exactly 6.92 cm from the probe. This solution is reliable and reproducible every time. It allows for a simple formula to be incorporated to ensure successful needle visualization, regardless of the age or complexity of the ultrasound machine. It is important to note that the center of the probe (not the edge) is the beginning point for the triangle's base measurement. Table 1 presents common needle angle distances developed on the basis of the law of sines. The new total distance to the target that the needle will have to travel is also included.

Target Depth	Insertion distance from probe	Distance to target from insertion site	Target Depth	Insertion distance from probe	Distance to target from insertion site
2.0 cm	3.2 cm	3.7 cm	6.5 cm	10.4 cm	12.26 cm
2.5 cm	4.0 cm	4.71 cm	7.0 cm	11.2 cm	13.20 cm
3.0 cm	4.8 cm	5.66 cm	7.5 cm	12.0 cm	14.15 cm
3.5 cm	5.6 cm	6.60 cm	8.0 cm	12.8 cm	15.09 cm
4.0 cm	6.92 cm	7.99 cm	8.5 cm	13.6 cm	16.03 cm
4.5 cm	7.20 cm	8.49 cm	9.0 cm	14.4 cm	16.98 cm
5.0 cm	8.0 cm	9.43 cm	9.5 cm	15.2 cm	17.92 cm
5.5 cm	8.8 cm	10.3 cm	10.0 cm	16.0 cm	18.86 cm
6.0 cm	9.6 cm	11.32 cm			

Table 1. Application Chart of the Law of Sines for Increased Needle Visibility During Ultrasound-Guided Regional Procedures

DISCUSSION

The benefits of incorporating this chart into clinical use are straightforward. Allowing users to see needles, even during deep structure targeting, may allow for increased safety and effectiveness for every technique. The formula is simple to incorporate and requires only one piece of information to use. This piece of information is the depth of the target structure. The depth is available on most clinical ultrasounds in use today. As an added, albeit unforeseen benefit of this discovery, the chart also reveals not only the point of entry that will enhance needle visibility but also the total distance the needle will be required to travel. This will simplify needle length selection before the start of a procedure.

Some problems may be associated with this technique. This chart or technique is difficult to use if the probe is placed in a position that may be difficult to measure accurately. Also, the region must be relatively flat in order to ensure relative accuracy of the formula. The technique described to increase visualization dictates the distance that the needle must be placed from the probe. As the target depth increases (albeit beyond most common clinical depths), such as beyond 6.5 cm, needles greater than 10 cm must be used. This may represent a special order item and may therefore increase cost or exclude use of the technique by centers that lack the necessary needle length. Increased needle distances may become uncomfortable for the patient, because it will become difficult to localize an area at great depth from the projected needle insertion site. It is difficult to assess or predict patient comfort in this arena, but an adequate volume of a fast-acting, dilute local anesthetic to the projected needle path may prove more comfortable for patients having deep injections. Another obvious deficit in this chart is the lack of necessary information regarding targets greater than 10 cm. However, it would be rare for a patient to require an injection or vessel access at this depth without another more feasible alternative. We recommend a formulated study to formalize these theoretical suggestions.

CONCLUSION

Ultrasound guidance has promoted increased effectiveness, and to some degree safety, during regional anesthesia techniques and vascular access.[12] We sought to produce and describe a technique that would simplify anesthesia providers' attempts to visualize needles during any regional or vascular procedure. We determined that by use of the law of sines, a simple distance could reliably be used to increase needle visualization during ultrasound-guided regional procedures. To use this chart, one only needs to know the target depth, and this seems to be available on most clinically used ultrasound systems. As shown in the table, many clinically relevant depths to target structures (ranging from 2 to 10 cm) can be used with reliable results. These results lead to increased needle visualization with the most primitive to the most complex ultrasound systems.

Acknowledgments

Special thanks to Bill Gordan, CRNA, for his assistance with this article.

REFERENCES

1. La Grange PDP, Foster PA, Pretorius LK. Application of the Doppler ultrasound blood flow detector in supraclavicular brachial plexus block. *Br J Anaesth.* 1978;50(9):965-967. http://dx.doi.org/10.1093/bja/50.9.965.
2. Marhofer P, Greher M, Kapral S. Ultrasound guidance in regional anaesthesia. *Br J Anaesth*. 2005;94(1):7–17. doi: http://dx.doi.org/10.1093/bja/aei002. Published online July 26, 2004.
3. Chan V, Perlas A. Atlas of ultrasound-guided procedures in interventional pain management. In: Chan V, Perlas A. *Basics of Ultrasound Imaging*. New York: Springer Science Business Media; 2011:13-19. doi: http://dx.doi.org/10.1007/978-1-4419-1681-5_2.
4. Reusz G, Sarkany J, Gal J, Csomos A. Needle-related ultrasound artifacts and their importance in anaesthetic practice. *Br J Anaesth*. 2014;112(5):794-802. http://dx.doi.org/10.1093/bja/aet585.
5. Schafhalter-Zoppoth I, McCulloch CE, Gray AT. Ultrasound visibility of needles used for regional nerve block: An in vitro study. *Reg Anesth Pain Med*. 2004;29(5):480-488. http://dx.doi.org/10.1097/00115550-200409000-00014.
6. Miura M, Kazuhide T, Toshiyasu S. Visibility of ultrasound-guided echogenic needle and its potential in clinical delivery of regional anesthesia. *Tokai J Exp Clin Med*. 2014;39(2):80-86.
7. Takatani J, Takeshima N, Okuda K, Uchino T, Noguchi T. *Ultrasound visibility of regional anesthesia catheters: An in vitro study. Korean J Anesthesio*l. 2012;63(1):59-64. http://dx.doi.org/10.4097/kjae.2012.63.1.59.